Materials Characterization

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Materials Characterization

- Goal: understand physical mechanisms responsible for failure
- Post-degradation analysis
  - Stress devices to failure
    - Look for changes in composition, structure, morphology, bonding, electronic behavior
    - Plan view and cross section
- Predictive characterization
    - Non-destructive
    - Wafer scale
    - Screen for materials related reliability problems before burn-in
    - Transferable to a variety of materials systems
- Small device dimensions are challenging

Post-degradation Analysis

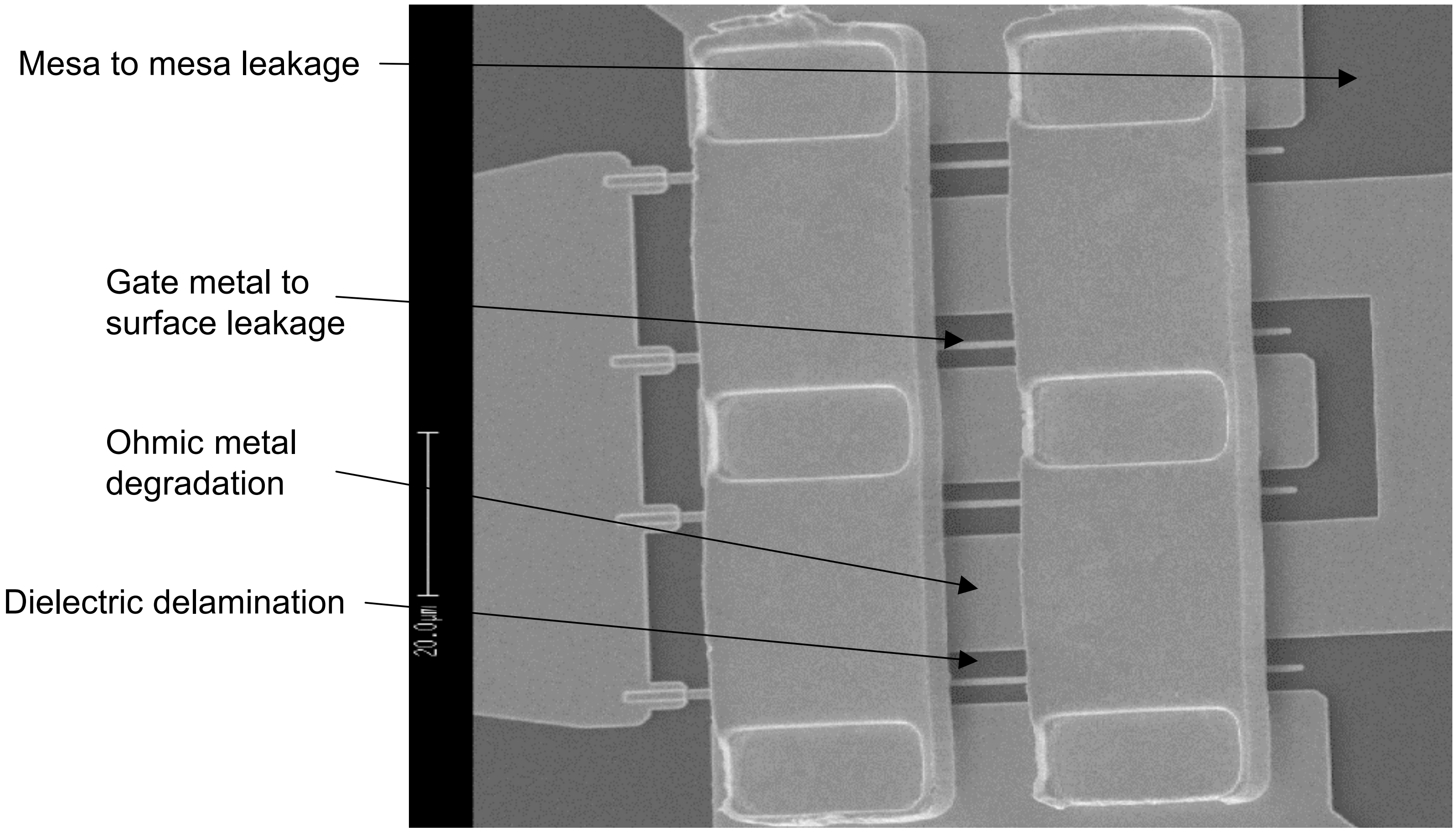
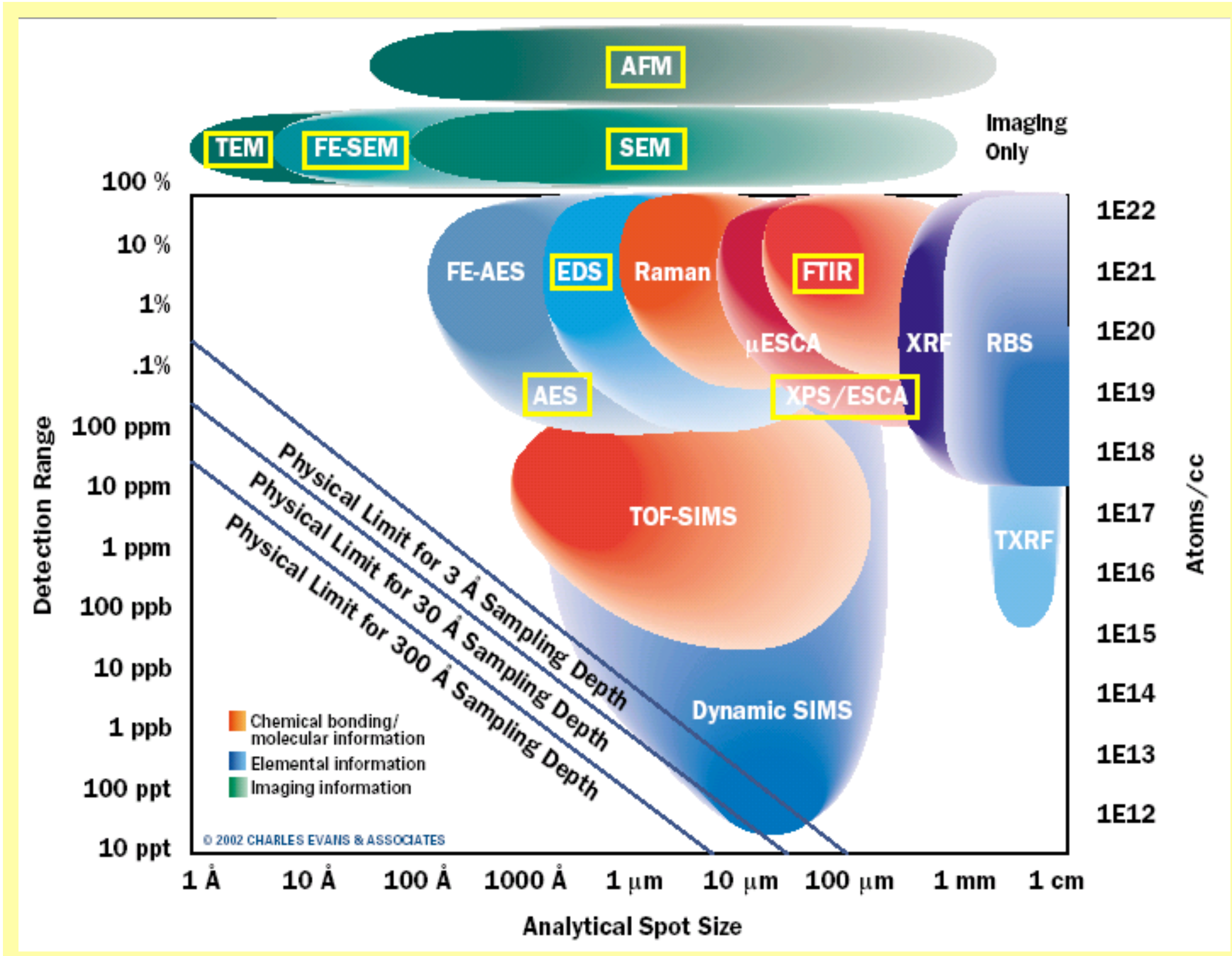


Image from the website of I. Adesida, UIUC

Analytical Instrumentation and Techniques



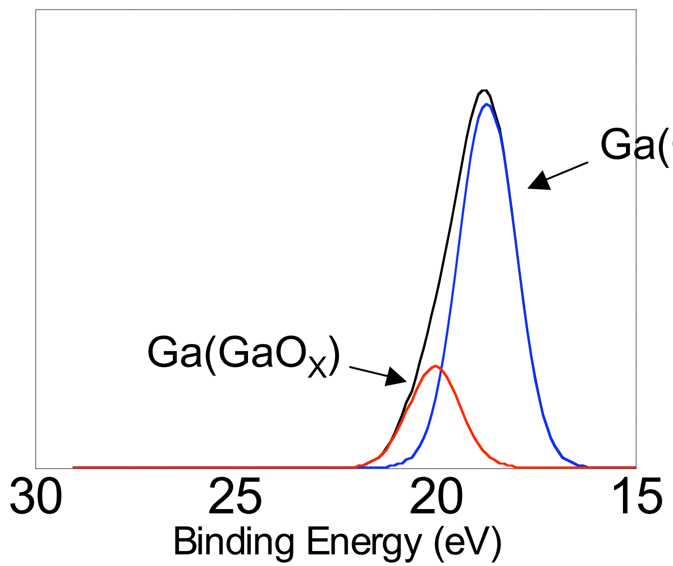
XPS/ESCA

X-ray photoelectron spectroscopy (XPS) or **Electron Spectroscopy for Chemical Analysis** (ESCA)

Chemical surface analysis method which measures the chemical composition of the outermost 100 Å of a sample.

All elements (except for H and He) can be detected at concentrations above 1.0 atom %. ; chemical bonding information can be determined from detailed analysis.

Useful for investigating surface phenomena such as dielectric passivation.



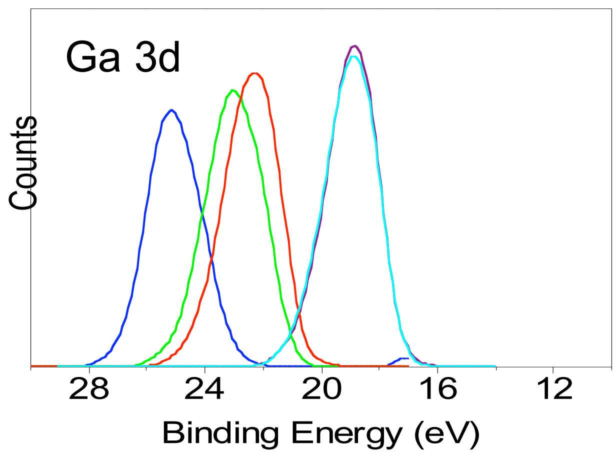
A Ga 3d peak with 2 curves fitted. Can determine relative concentration of Ga-O and Ga-N

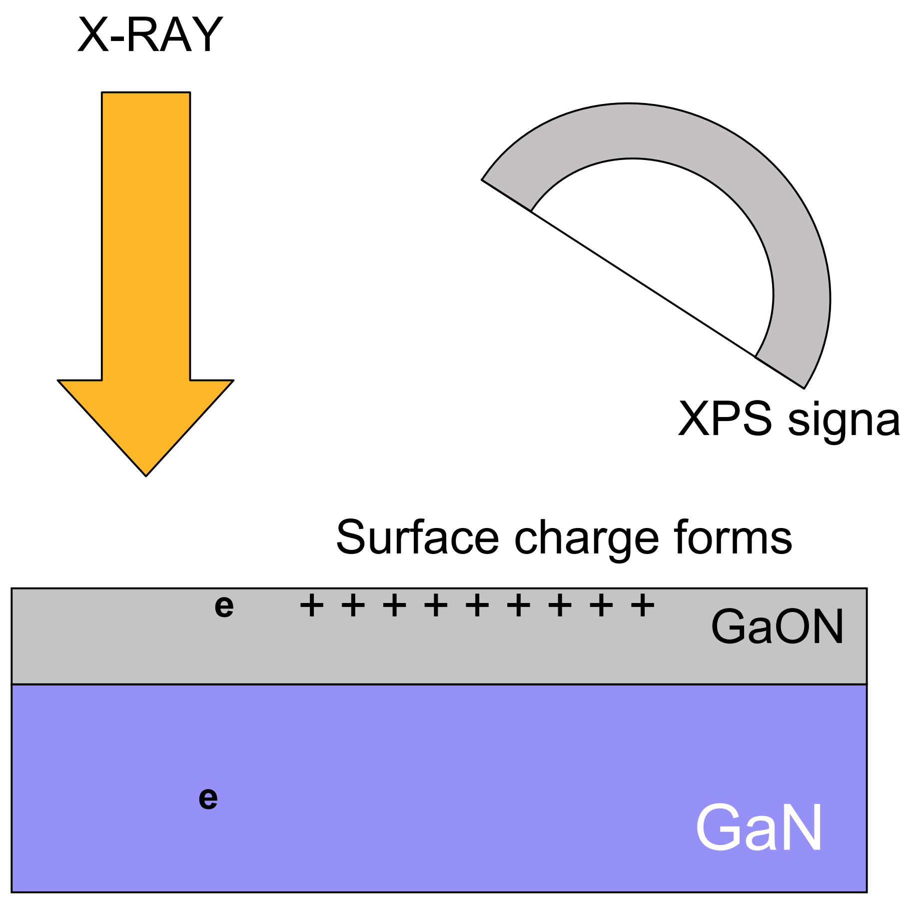
Past XPS use on HEMT passivation optimization

As x-rays enter the material, photo-electrons are generated from different depths.

Thick (2nm) ozone GaON is **not** conductive; electrons leaving the surface are **not** replenished from the bulk.

Large surface charge (4.8eV) **is** indicated from XPS spectra shift.



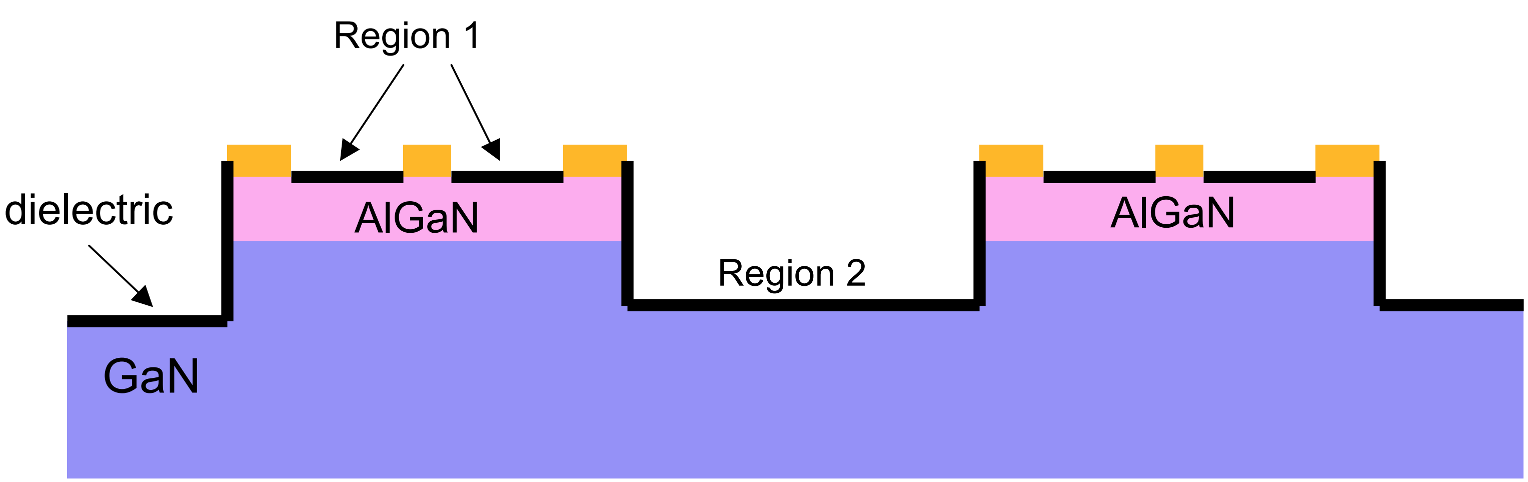


Plan for Investigation of Dielectric Reliability

Reliability (aging) of the dielectric can be determined through both thermal stress and bias stress to determine method of failure. (large area features)

The two regions for dielectric coverage have significantly different surface chemistries and structure.

Identify key interface species/reactions that lead to stable passivation, isolation or field plate dielectrics.



Ultraviolet Photoelectron Spectroscopy

Used for studies of the valence electron density of states.
VUV (10-200nm) discharge covers range from 10 to 50 eV photon energy.
Line width of excitation is generally a few meV, excellent for resolving molecular vibrational structures.

Provides a high resolution valance band spectra compared to XPS for determining valance band on surfaces.

Changes in band bending (passivation) in the near surface region can be determined.

XPS/UPS/MBE System Capabilities

Analysis Chamber

PHI 5400 XPS :

- X-ray source excitation: Mg Kα (1253.6 eV) or Al Kα (1486.6 eV)

1 mm spot size

UPS:

- UV source excitation: He I (21.2 eV) and He II (40.8 eV) radiation lines

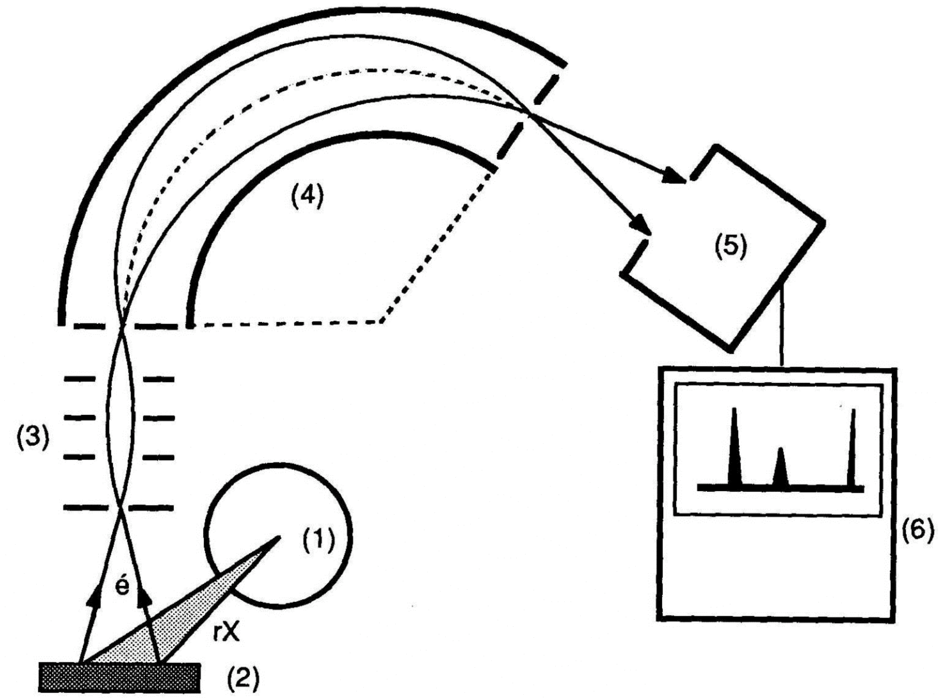
Additional Equipment:

- Sputter ion gun (Ar)
- Sample heater up to 700°C
- Electrical feedthrough for bias aging

MBE Chamber

Ga, Al, N plasma, H plasma, Si, Mg

RHEED

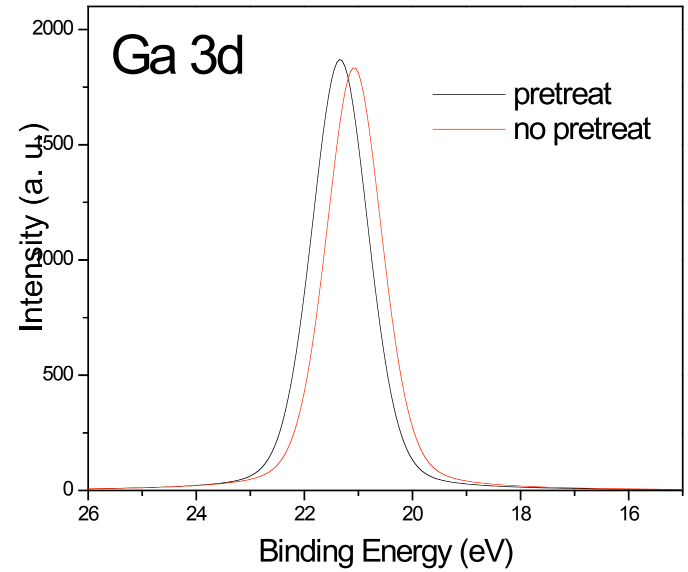


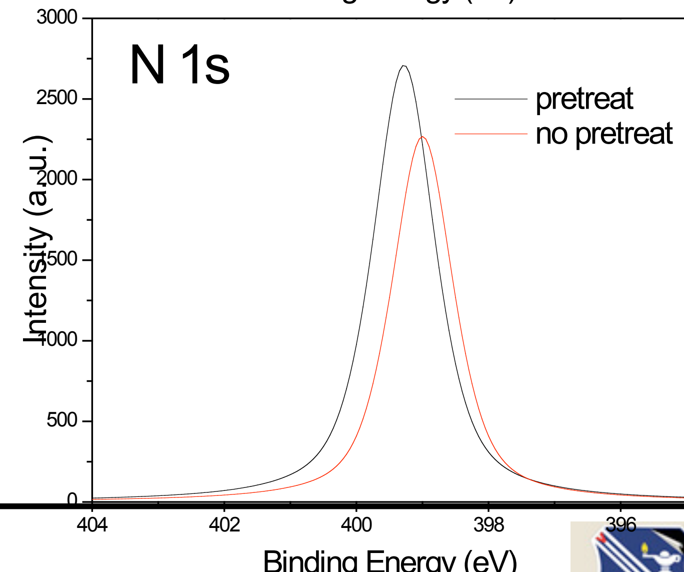
XPS System Schematic:

1. X-ray source – Mg or Al anode
2. Sample
3. Lens and aperture
4. Hemispherical precision energy analyzer
5. Position Sensitive Detector
6. Data Collection - Computer

GaN Surface Cleaning Study

- Cleaning Procedure:
  - 1:1 HCl:H_2O submersion for 3 minutes
  - Rinse sample in DI H_2O, dry with N_2
  - UV ozone (O_3) exposure for 25 minutes
  - BOE submersion for 5 minutes
  - Rinse sample in DI H_2O, dry with N_2
- Increased signal; shift may be due to surface charging after removal of contaminants
- Plan to study effect of temperature on surface band bending as a function of surface treatment
- UPS installed; operational next month
- Can integrate with oxide MBE via vacuum briefcase for controlled oxidation studies

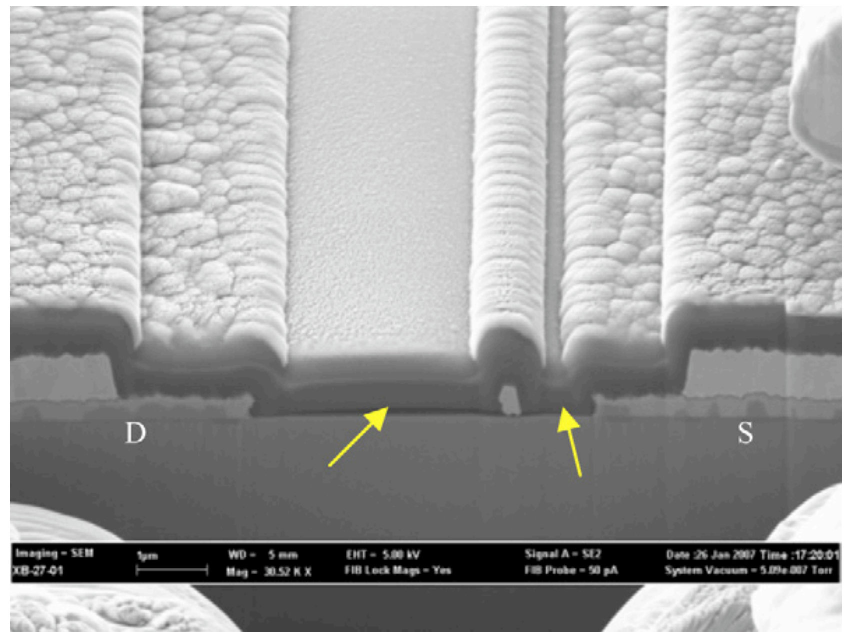




Scanning Electron Microscopy

- **JEOL JSM 6400, JEOL JSM-6335F, FEI XL-40**
  - Energy Dispersive Spectroscopy (EDS)
  - Cathodoluminescence (CL)
  - Electron Backscatter Diffraction (EBSD)
  - Electron Probe Microanalysis (EPMA)

- SEM based techniques
  - Overlay large area spatial maps of microstructure (SE), composition (EDS) and radiative efficiency (CL)
- SEM of cross-section
- FIB sample preparation to minimize sample prep damage

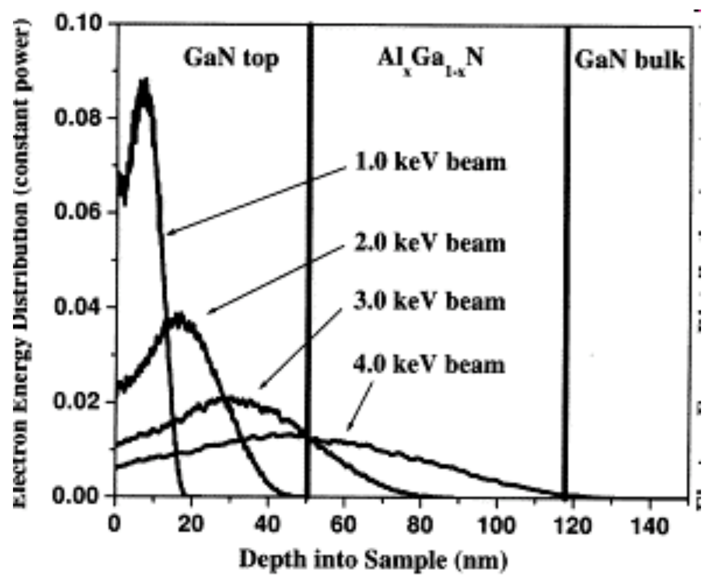


Example of dielectric delamination

M. Bouya et al., Microelectronics Reliability 47 (2007) 1630–1633

Cathodoluminescence (CL)

- Emission of ultraviolet, visible and infrared photons from a solid resulting from excitation by electrons
- Panchromatic and monochromatic
- Excitation depth varies with electron voltage
  - Emission decreases with decreasing voltage
- Used in Si device technology to identify locations of metal failures
- Shown to be useful in screening III-N material for performance of Ohmics and SBH
- May correlate with long term reliability issues



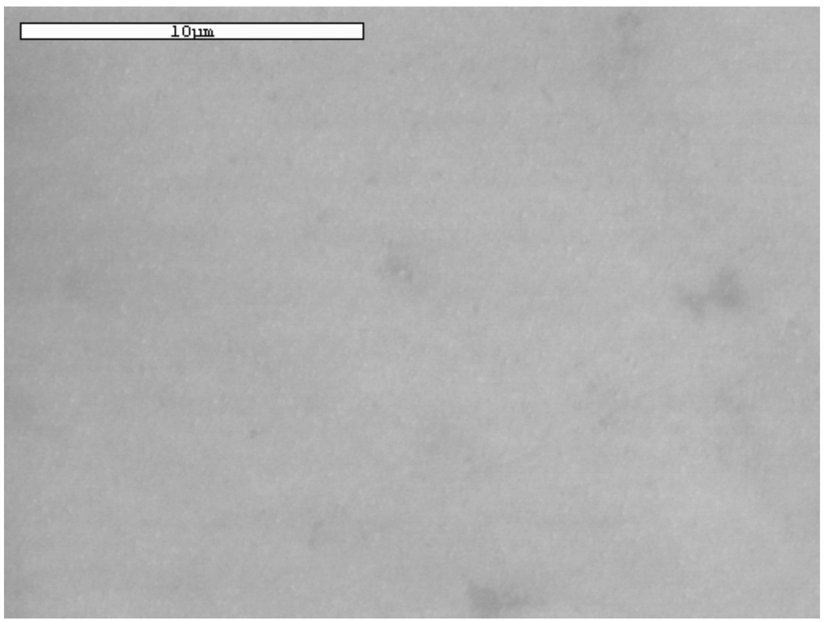
G. H. Jessen , et. al., Solid-State Electronics, Vol. 46, 1427.

Plan For Reliability Studies Using CL

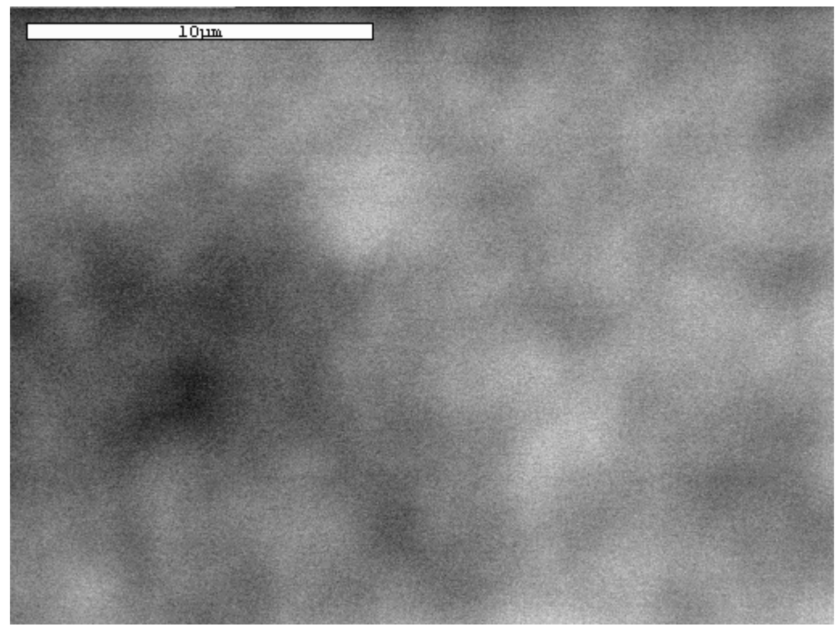
- Plan view scans of device regions before and after degradation
  - E.g. look for defect density changes along gate edge
- Remove metal after various processing steps and after failure
  - Correlate changes in spatial distribution with EDS to investigate relationship between metal migration and failure
- Can also be done in cross-section
- Map defect spectra across wafer before processing
  - Probe point and line defect distributions
- Correlate with subsequent device failures
- Develop QC metrics to bin wafers before and/or during processing
- Monochromatic CL required to differentiate defect types

Panchromatic CL at UF

- Gatan PanaCL high collection efficiency (>75%) Cathodoluminescence (CL) imaging system
  - retractable mirror; wavelength range 185-850 nm
- AlN removed from Si substrate
  - Regions of inhomogeneity not seen in SE mode
- Analysis of metallized regions shows no evidence of redistribution of CL emission



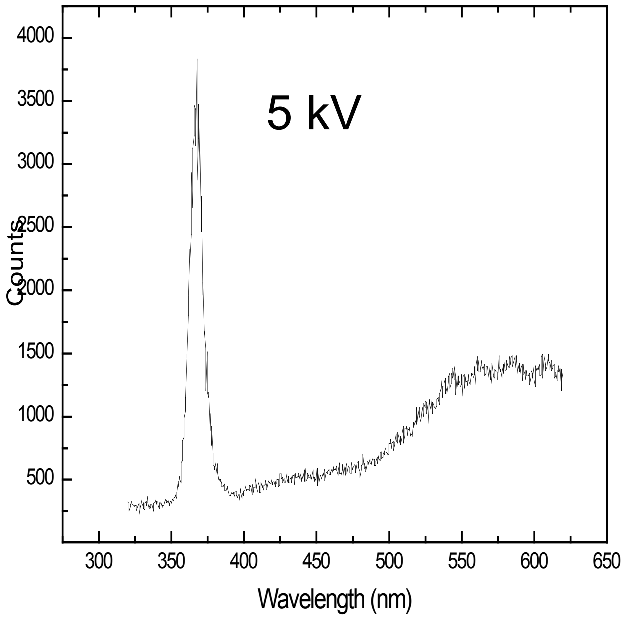
SE



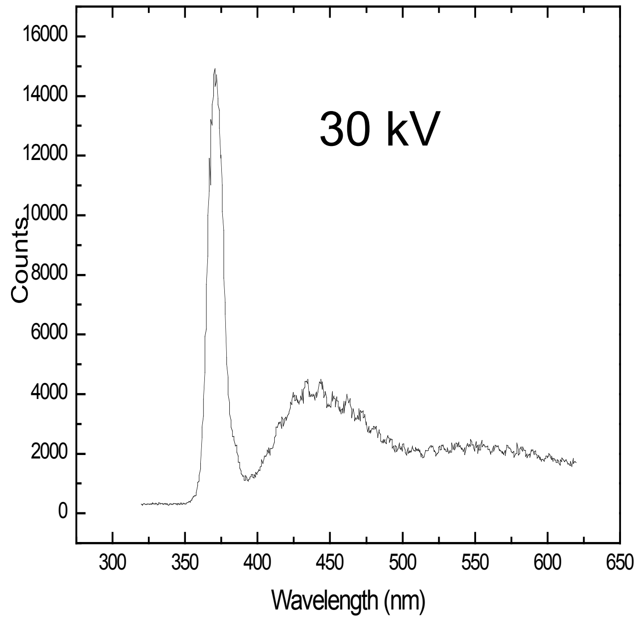
CL

Depth Dependence of Emission Spectra (GaN Region)

UCF Chernyak System from GaN/AlGaN HEMT



~80-100nm below surface

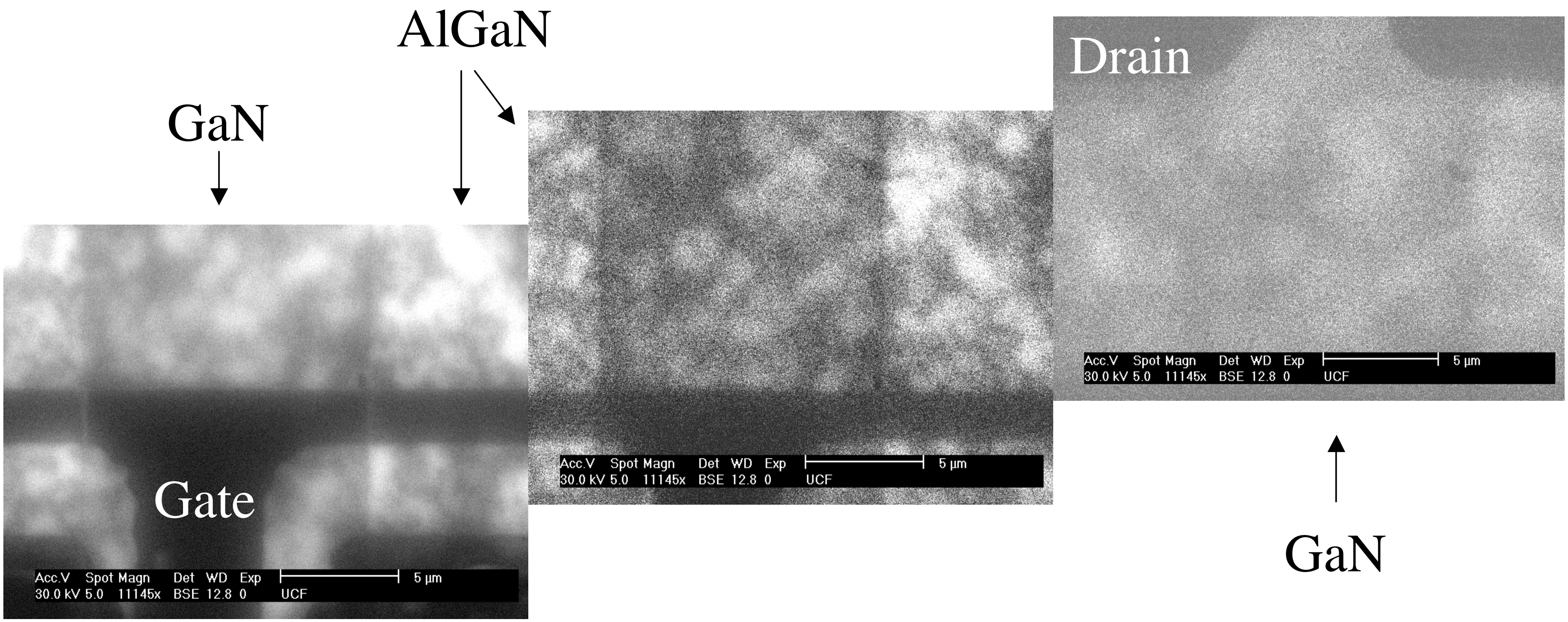


GaN Buffer

Wavelength Dependence of CL Emission

30 kV, 11kX

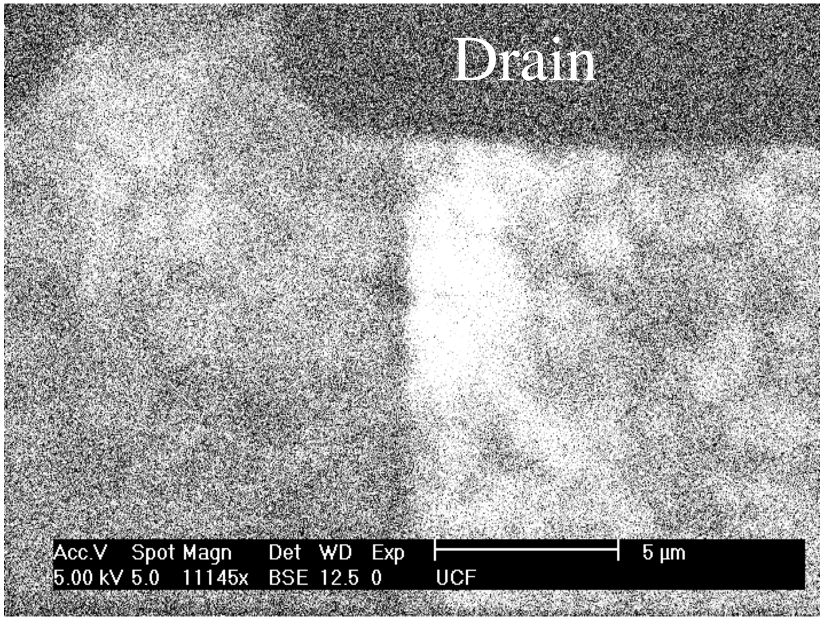
Panchromatic | Bandedge | 440 nm



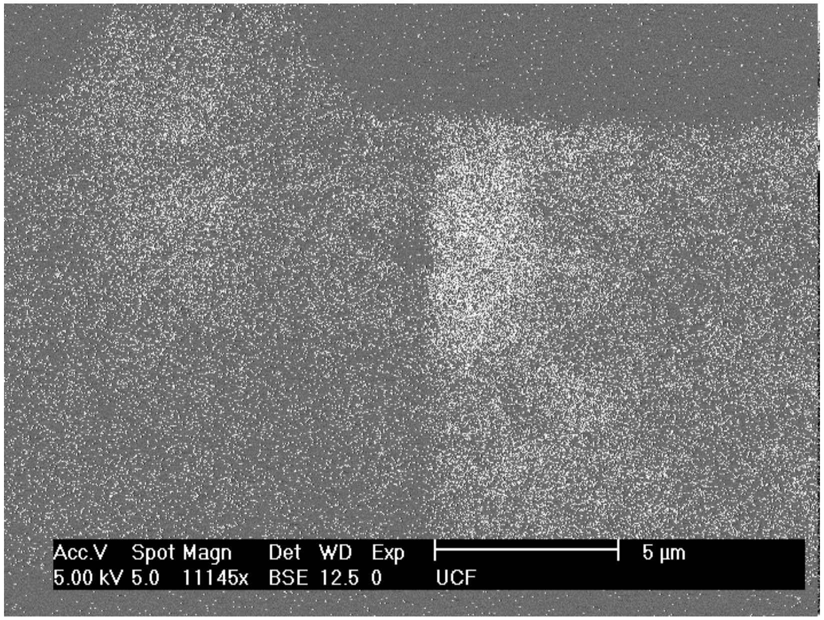
Wavelength Dependence of CL Emission

5 kV, 11kX

Panchromatic



Bandedge



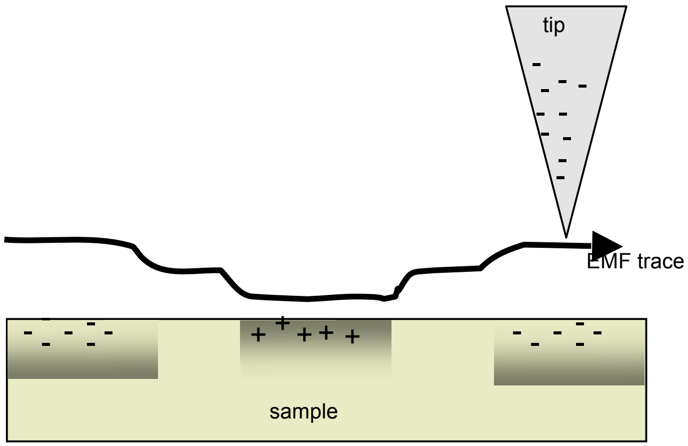
Need FE SEM and MonoCL3 to improve sensitivity and resolution

CL Equipment Available for Project Use

- UF MAIC
  - FE SEM with Gatan PanaCL
- UCF Physics
  - Phillips SEM/Gatan MonoCL
  - Dr. Leonid Chernyak, UCF
- UCF Materials
  - FE SEM with Gatan MonoCl3
  - Available Late April
- UF NIMET
  - Nano characterization tool
    - FE SEM with Gatan MonoCL3
    - EDS
  - Available January 2010

Electrostatic force microscopy - EFM

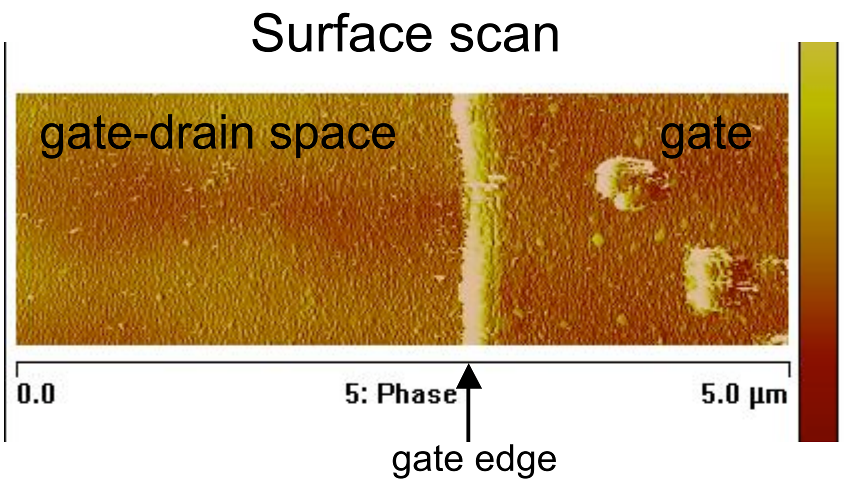
Scan area in AFM Tapping Mode, then apply a bias to the tip and scan in EFM mode. The z difference of the two scans corresponds to a change in electric field.

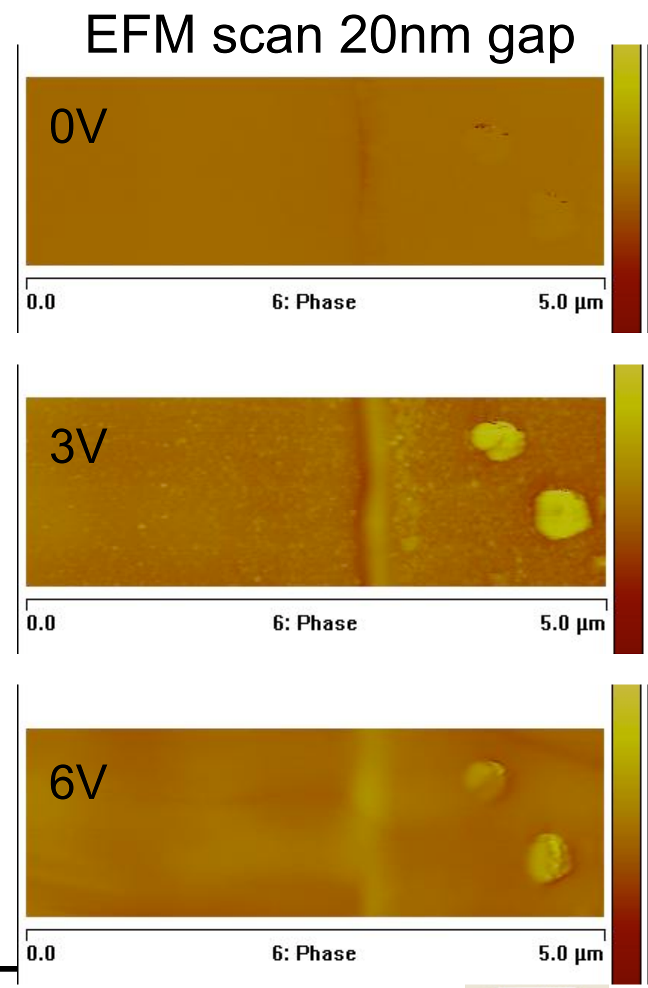


Veeco Dimension 3100 with Nanoscope V controller is currently installed in the MAIC facility

Electrostatic force microscopy - EFM

Applied to pre and post aged devices to scan for variations of the electric field on the device surface.

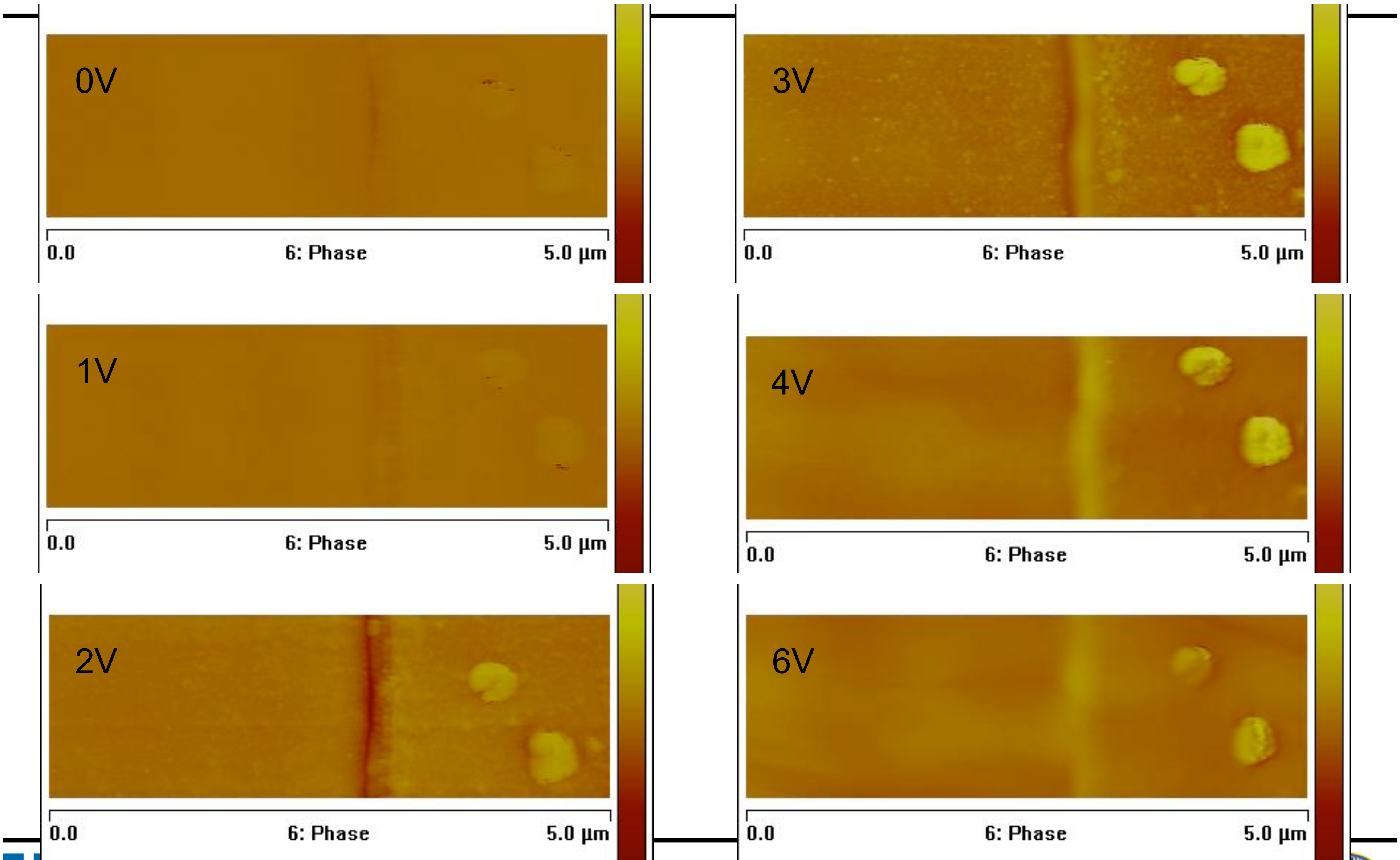




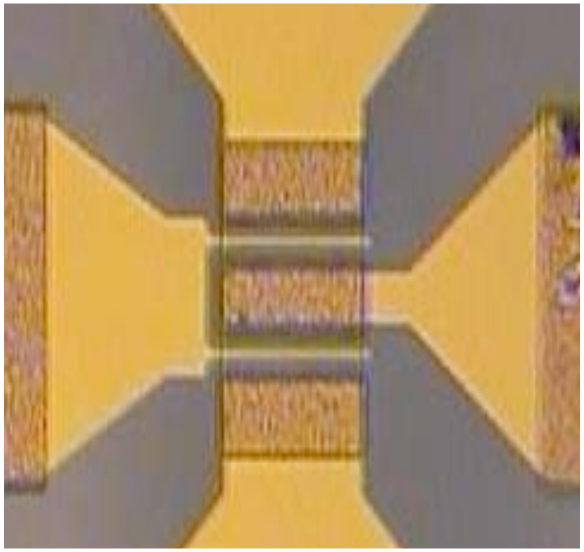
As tip bias increases, resolution increases until the tip electric field is larger than the surface features, then resolution decreases.

Optimum voltage required for resolution.

Changes in resolution with changes in tip bias.



Electrostatic force microscopy - EFM

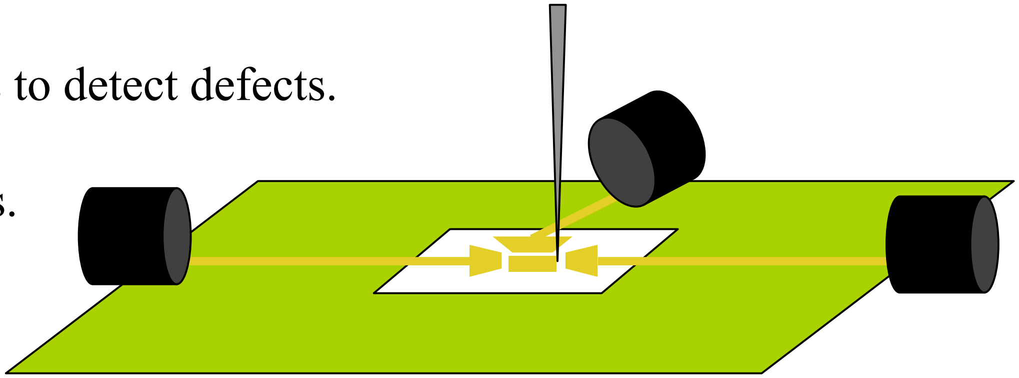


Applied to pre and post aged devices to scan for variations of the electric field on the device surface.

Examine defects propagating to the surface during testing, electromigration of gate metal in the gate-drain region, and increases in the surface potential from UV illumination emptying traps.

Identify area for TEM/LEAP.

Drawback, device must be under SD bias to detect defects. This provides an electric field from the device and the tip will be at different bias. Defects become visible.



Conductive AFM

- Similar to EFM but may have a higher resolution (no electric field to decrease resolution).
- Defects detected without the device under SD bias
- Measures a dc current between a tip under bias and the sample at ground
- Changes in current are plotted in xy coordinates over a topographical AFM map.
- Defects seen as a change in current.
    - Threading dislocation shows a higher current than a defect free region (leakage path).
    - Changes in vacancy concentration should also be seen as a change in current (doping change).
    - Electromigration of metal from the gate to the drain is also easily detected.
- DC test card under design for EFM. Requires unpackaged DIE mounted and wire bonded to card for SD biasing. Not required for Conductive AFM.